Neuroergonomics

Analyzing Brain Function to Enhance Human Performance in Complex Systems

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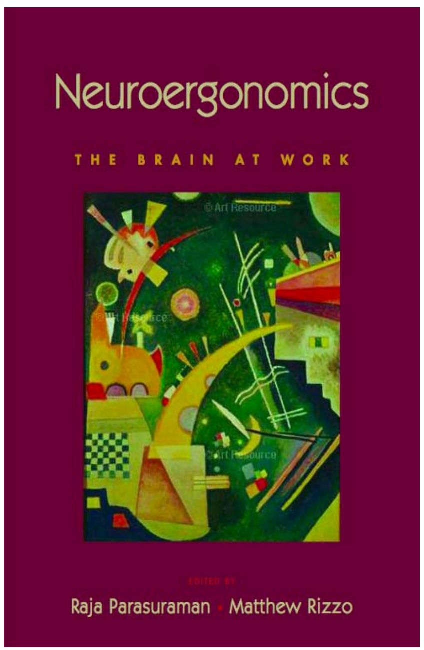
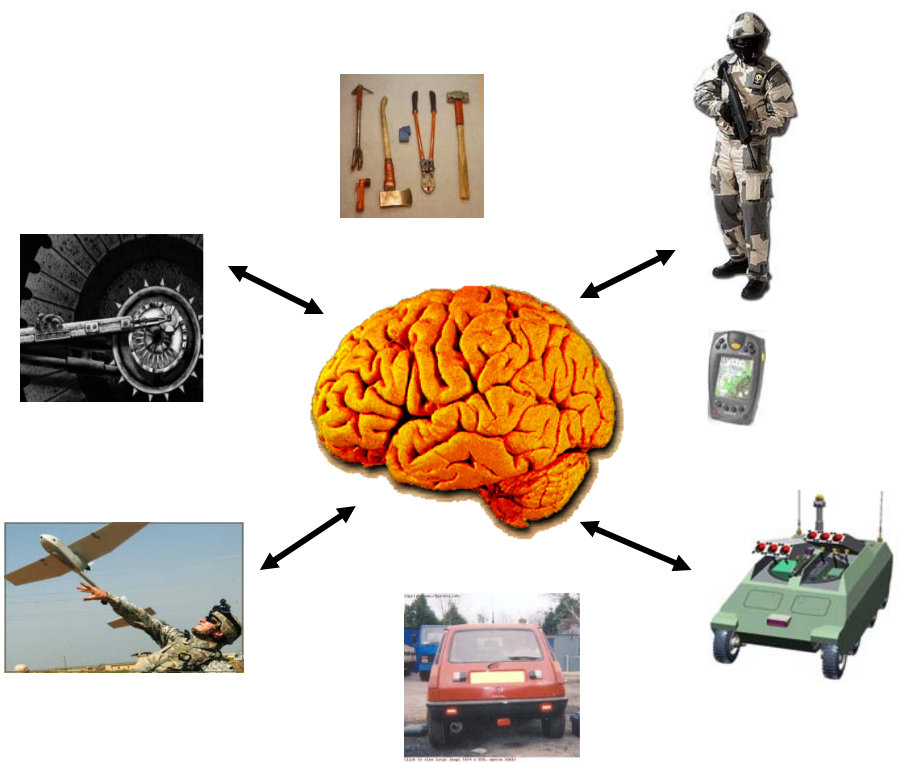
Why Neuroergonomics?

- To design effective human-machine systems, we must
  - ➢ Understand mind in relation to work and technology—ergonomics
  - ➢ Mind cannot be understood without studying the brain—neuroscience
  - ➢ Hence study brain and mind in complex work domains—**Neuroergonomics**
- Neuroergonomics can provide for more effective and natural interaction between humans and technology



Oxford University Press, 2008



Two Examples of Neuroergonomics

- **Neuroimaging and adaptive automation**
  - Enhancing performance of operators supervising multiple unmanned vehicles
- **Molecular genetics and proteomics**
  - Identifying rapid decision makers in command and control

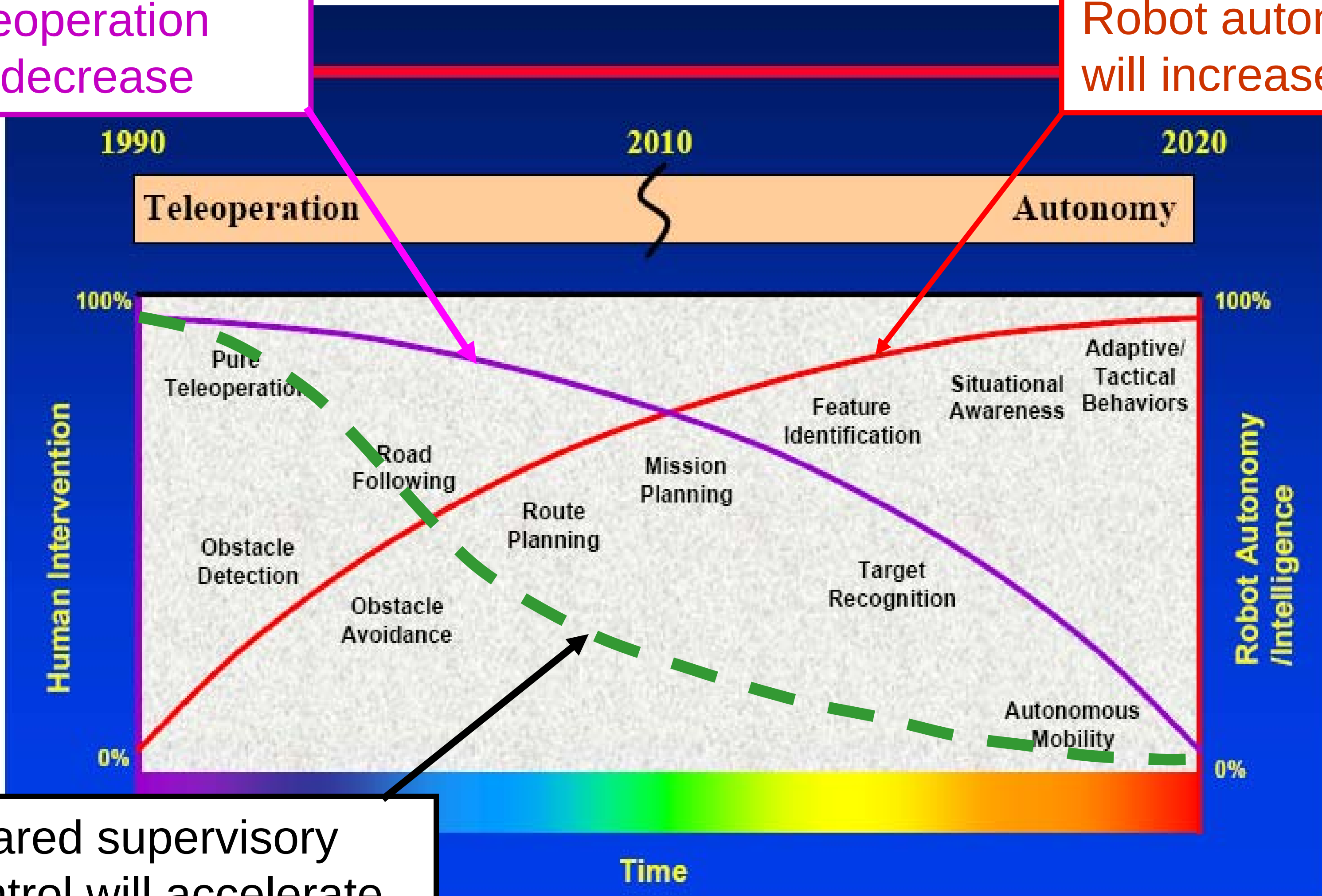
Example 1:
Neuroimaging and Adaptive Automation

Enhancing performance of operators supervising multiple unmanned vehicles

Robotic Evolution Overview*

Teleoperation will decrease

Robot autonomy will increase

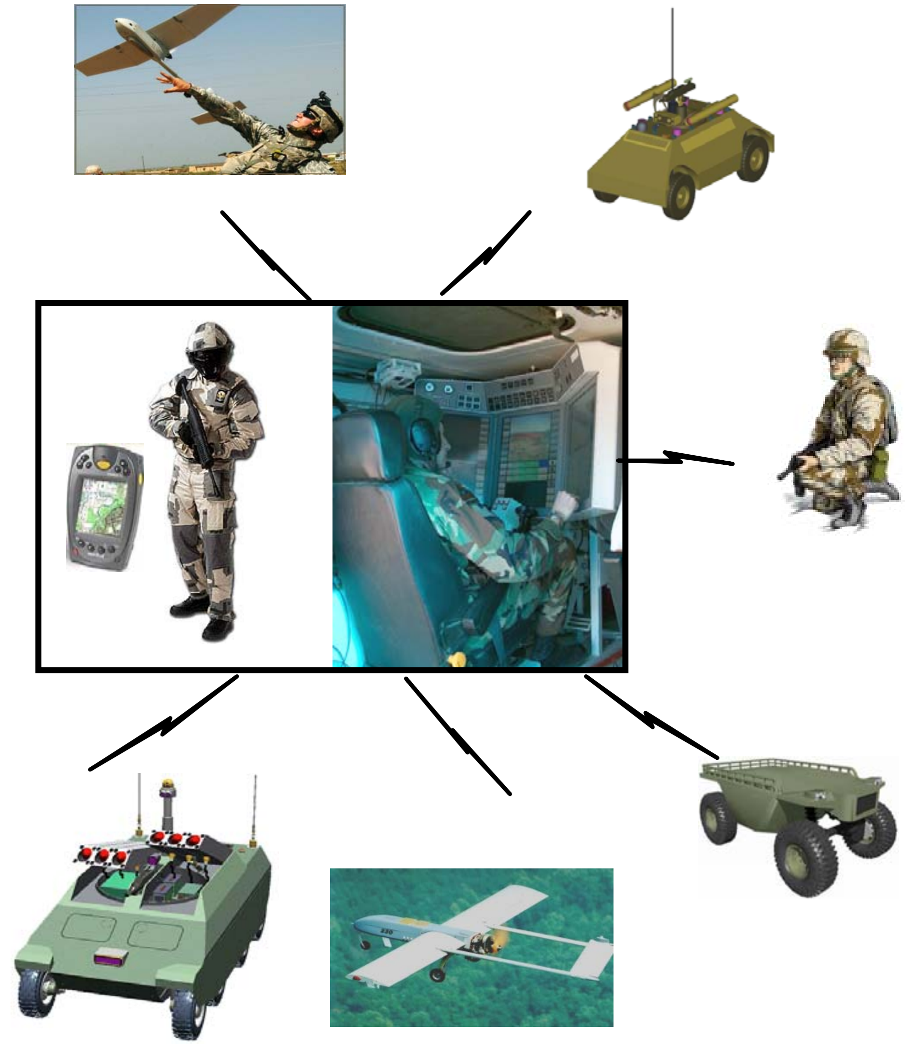


Shared supervisory control will accelerate transition

*** 2005 Joint Robotics Program Master Plan**

Soldier-Robot Teaming

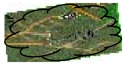
- Unmanned vehicles being introduced in Army systems to
  - extend manned capabilities
  - provide tactical flexibility
  - act as "force multipliers"
- Goal: Enhance Soldier-system performance while optimizing workload
- Approach: Use **adaptive automation** to provide support to Soldier when and where needed



Adaptive Automation

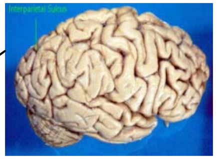
An approach to automation in which the "division of labor" between human and machine is flexible and context-dependent

Optimized user performance



User engaged in a cognitive task

Operator Assessment



Cognitive Workload Assessment

Task Context

Cognitive Events

Adaptive System Manager

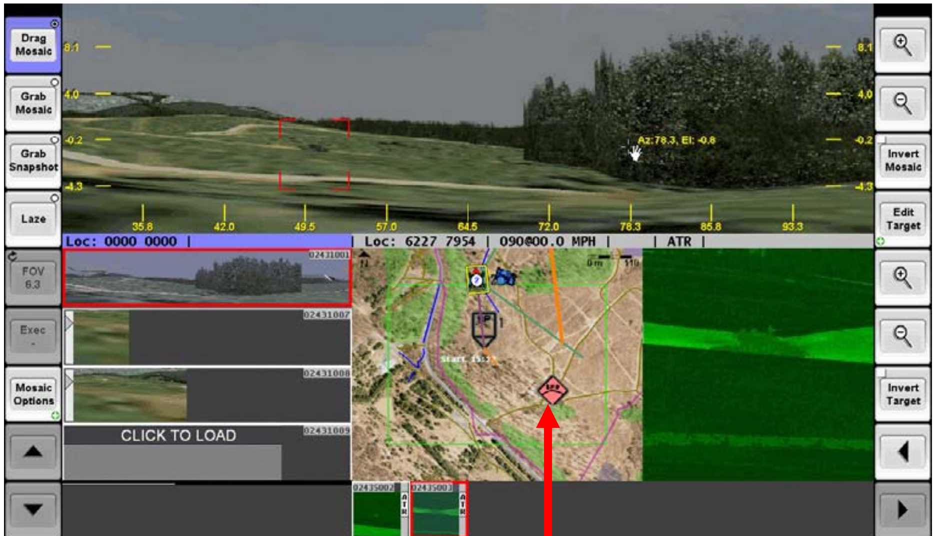
Adapts Interface Behavior

Triggers for Adaptive Automation

- Critical events
- Mission phase
- Operator performance
- User modeling
- Operator neurocognitive states (attention, workload, situation awareness, fatigue etc.)

Parasuraman (2000), *Ergonomics*.

Simulation Integration Lab (SIL)



- Reconnaissance, Surveillance, and Target Acquisition (RSTA)
  - ➢ With and without Automatic Target Recognition (ATR) support
- Monitor UAV and UGV assets
- Secondary change detection task

Change Detection Task: Icon on Situation Map Moves

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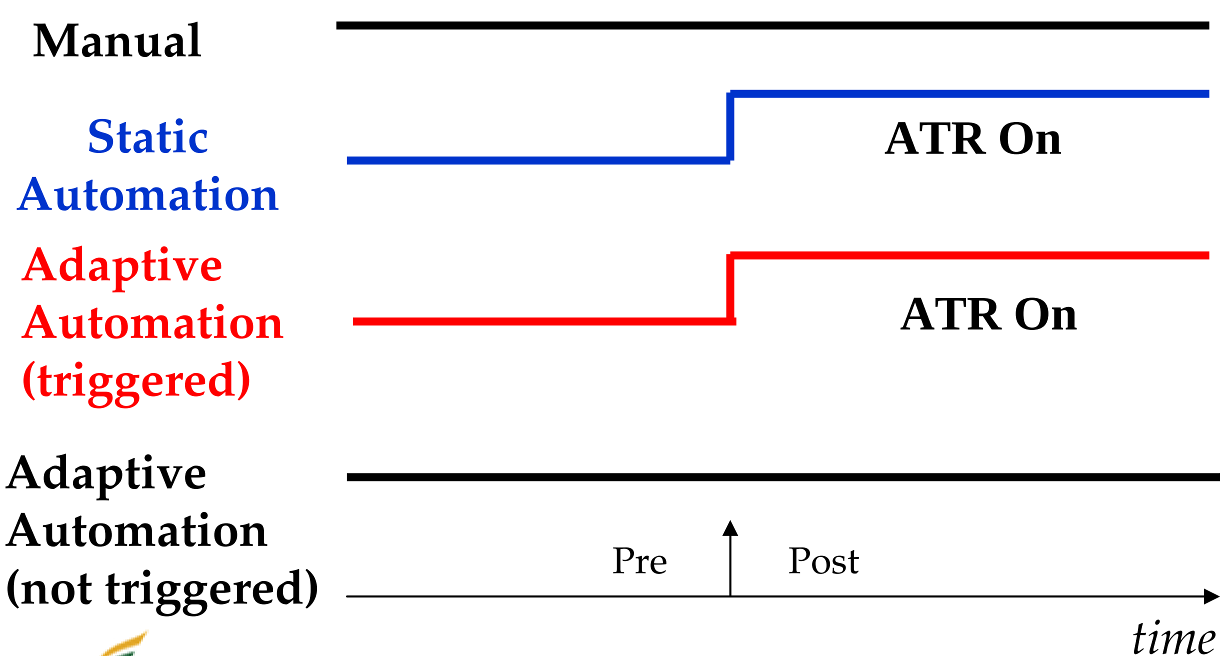
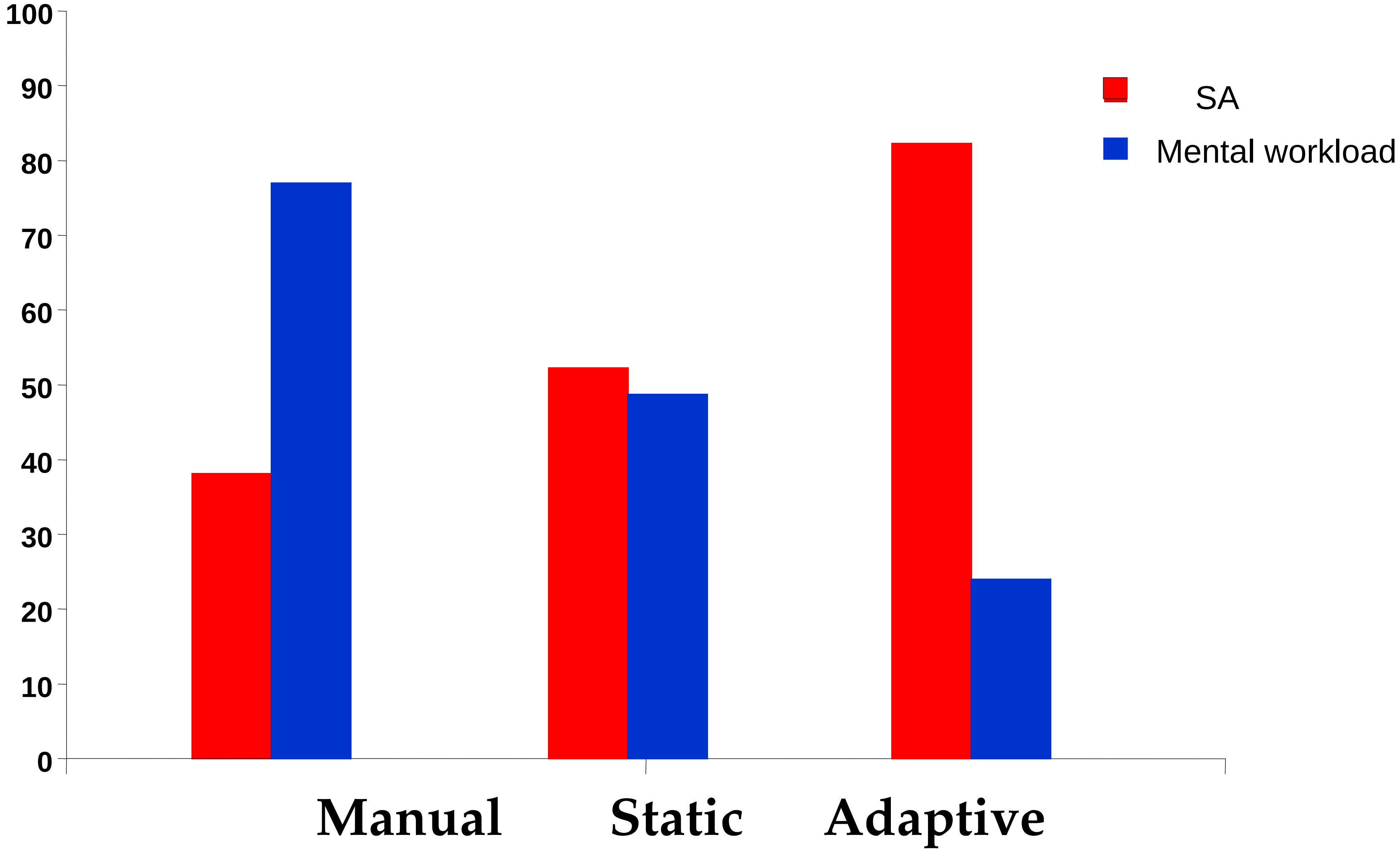
Testing the Efficacy of Adaptive Automation

- **Manual: no support**
- **Static automation: Automatic Target Recognition (ATR) in middle of simulated reconnaissance mission**
- **Adaptive automation: Automatic Target Recognition (ATR) in middle of simulated mission**
    - ***if and only if* subject's change detection performance up to that point in time is less than a threshold**

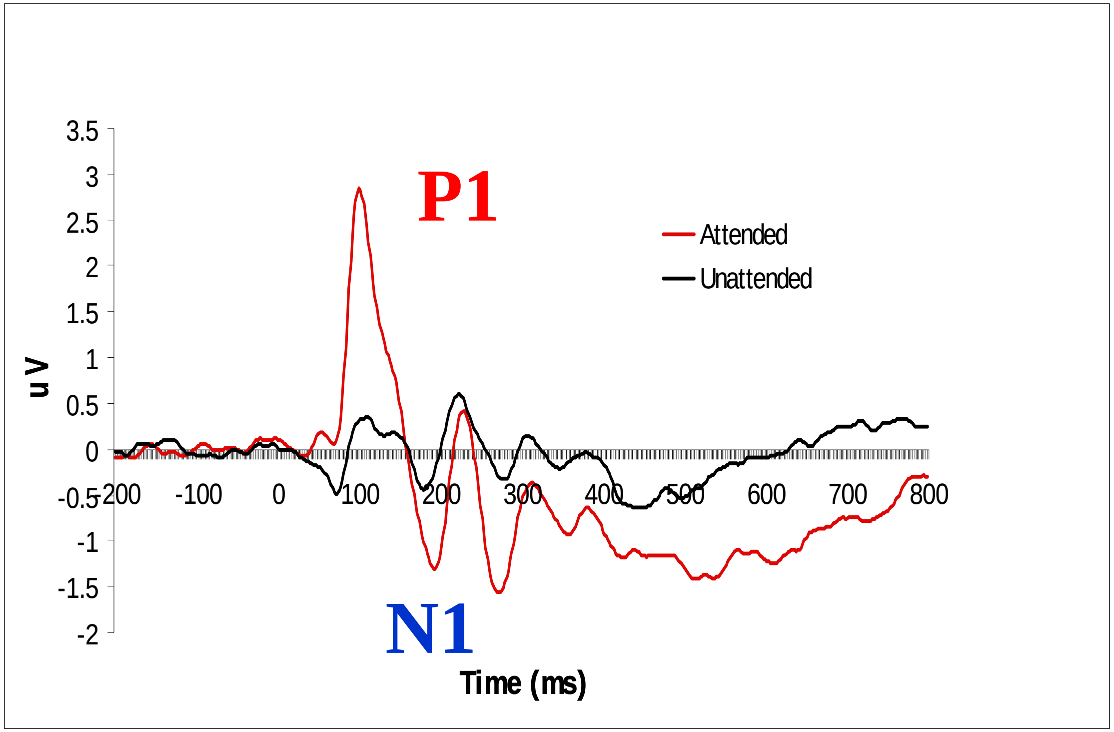


Effects of Adaptive Automation on Situation Awareness (SA) and Workload

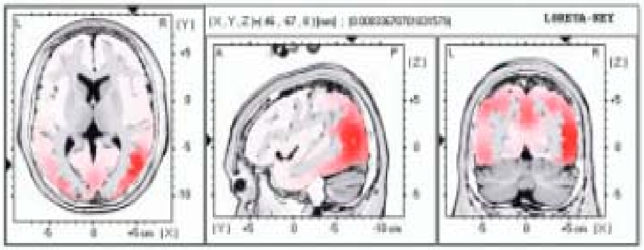


Attention Enhances the P1and N1 Event-Related Brain Potential Components

ERPs and Attention



Brain Topography of Attention Effect



Fu, Greenwood, & Parasuraman (2005), *Human Brain Mapping*

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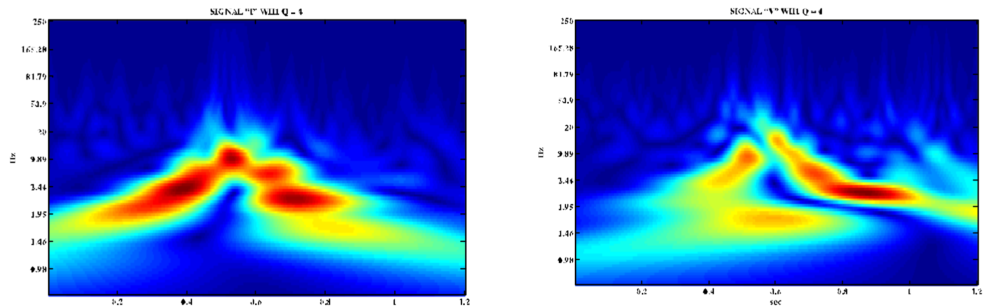
Event-Related Brain Potentials (ERPs) to Attended and Unattended Probes

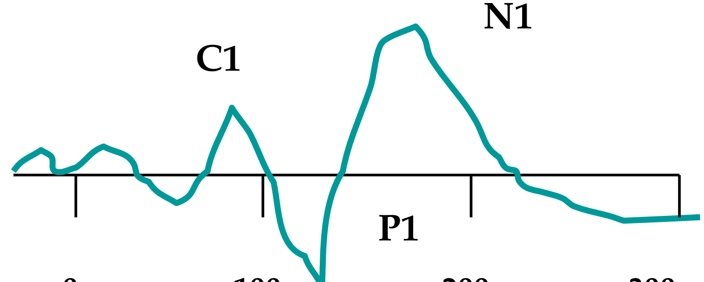
**Change detection probe:
Sine wave grating**

Wavelet analysis



Attended Probe **Unattended Probe**

ERP to Probe Event



Time (milliseconds)

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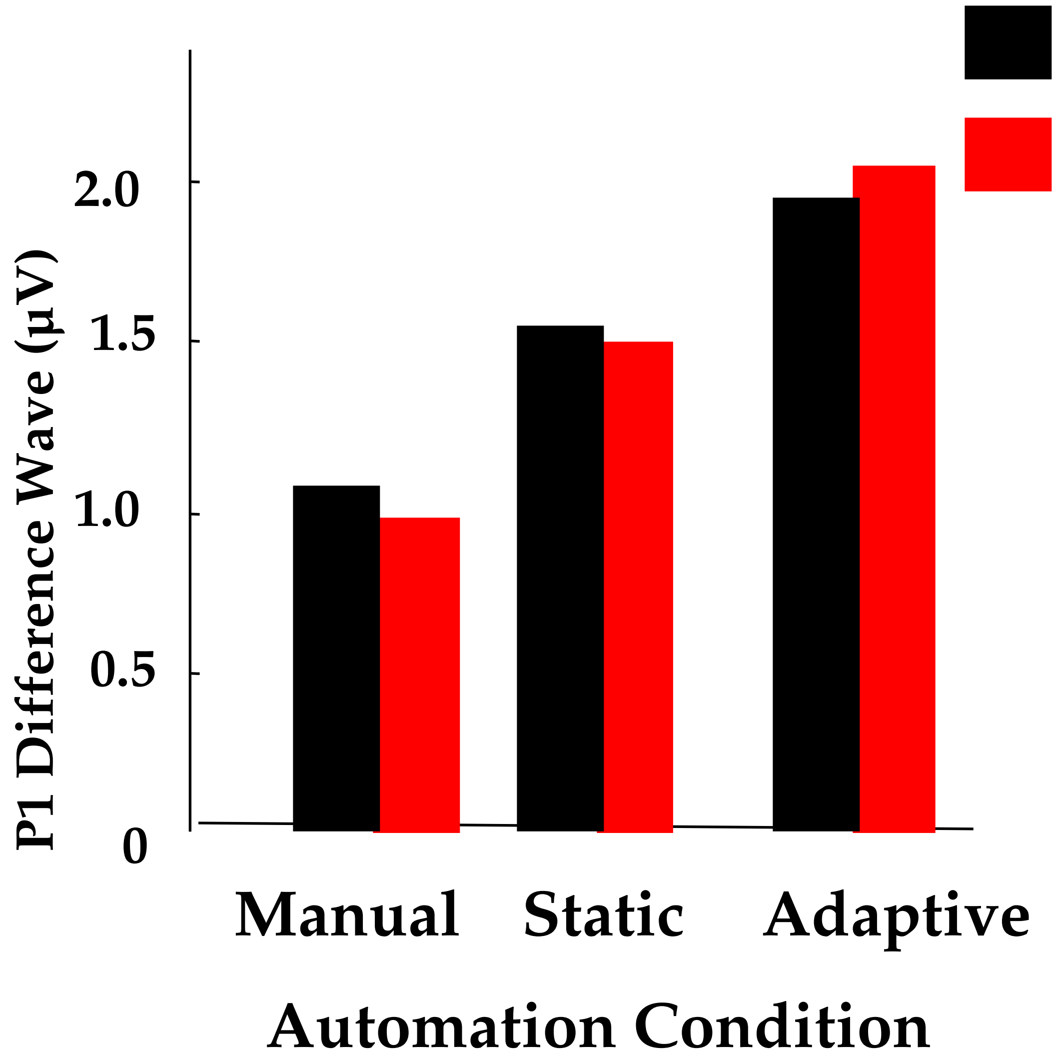
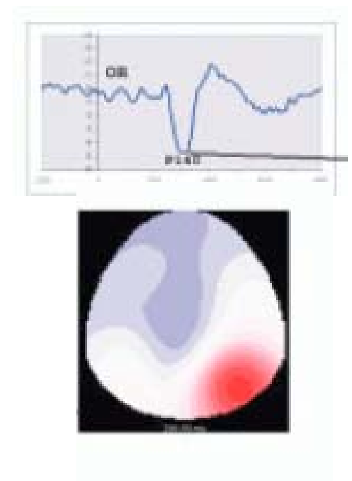
Effect of Adaptive Automation on the P1 Brain Potential Attention Effect





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Example 1: Conclusions

- **Adaptive automation triggered by operator change detection performance enhances human performance in multiple UAV/UGV supervision—increased SA and reduced workload**

- **Brain measures of attention (P1 and N1 components of the ERP) provide converging neural evidence for the efficacy of adaptive automation**

- **A neuroergonomic approach to adaptive automation can lead to improved human-machine synergy**

  - **Licklider's (1960) vision of human-computer *symbiosis?***

Example 2:
Molecular Genetics and Proteomics

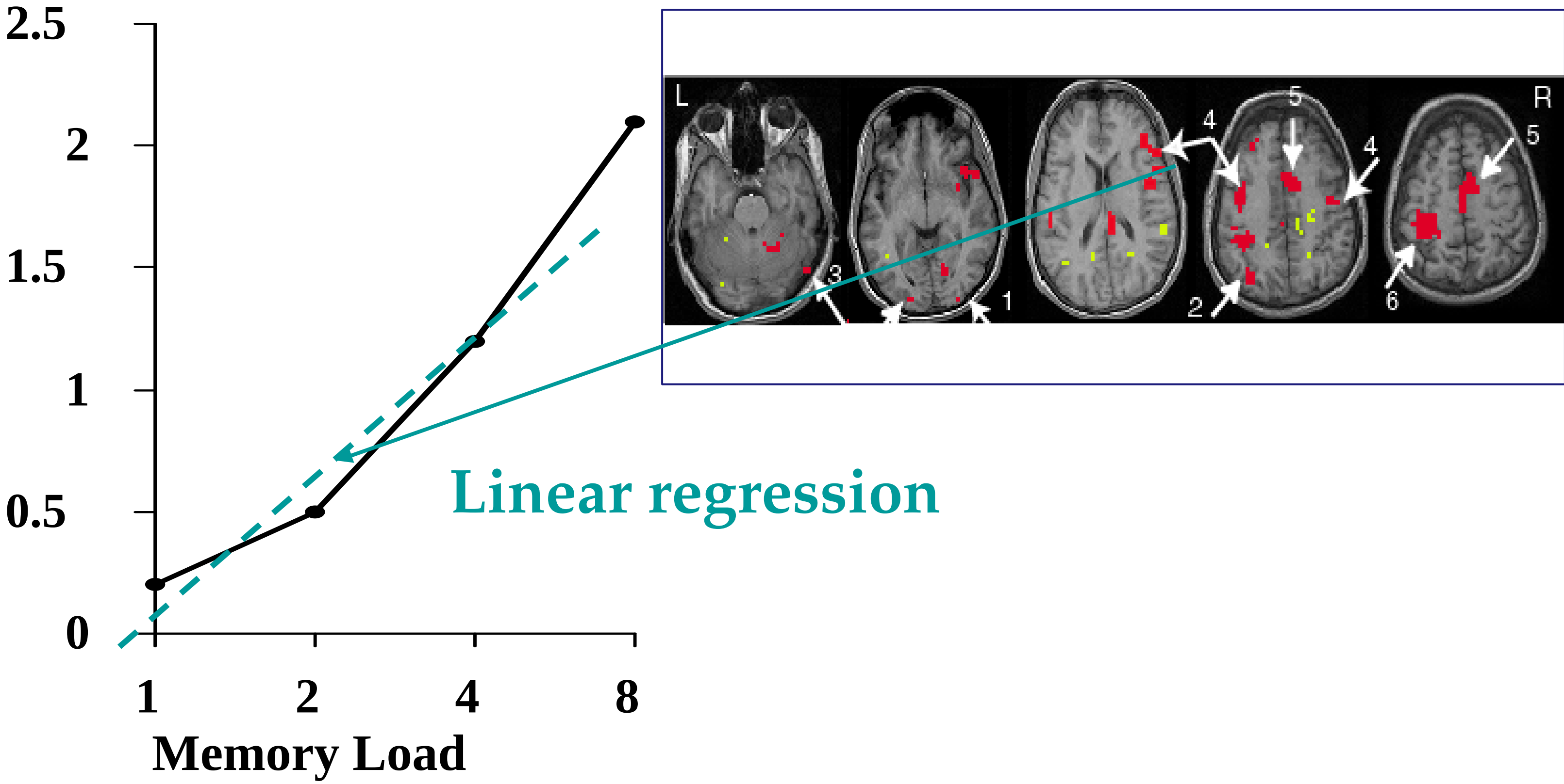
Identifying rapid decision makers in command and control

Identifying Sources of Individual Differences

- **Individual differences reflect**
  - **Development**
  - **Experience**
  - **Training**
  - **Genetic factors (natural variation)**

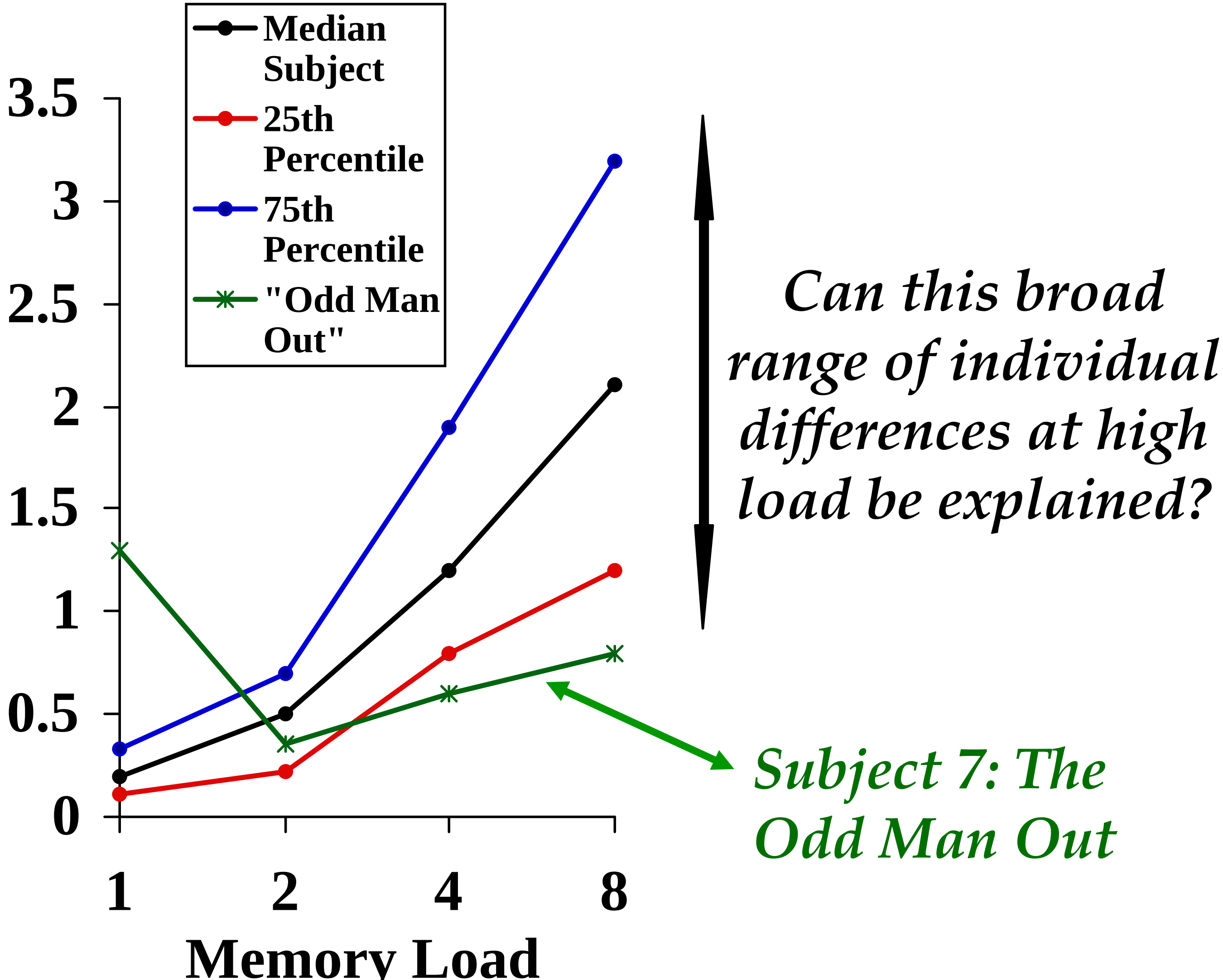
- **Can molecular genetics help in understanding**
  - **Normal variation in cognition?**
  - **Exceptional individuals ("cognitive superstars")?**

Effects of Working Memory Load on Prefrontal Cortex Activation



Jiang, Haxby, Martin, Ungerleider, & Parasuraman (2000). *Science*

Prefrontal Cortex Activation and Working Memory Load



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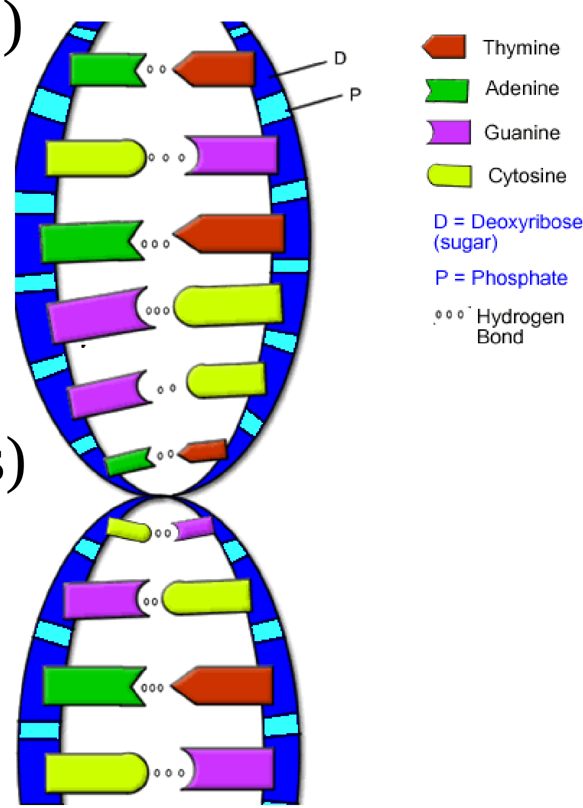
Genes, DNA, and SNPs

- Human genome: ~ 20-25,000 genes
  ~ 3 billion DNA base pairs (bp)
- The DNA alphabet
  - thymine (T)
  - adenine (A)
  - guanine (G)
  - cytosine (C)
- DNA base pairs can have different forms (alleles)
- Allelic variation often due to substitution of one amino acid for another—single nucleotide polymorphisms (SNPs)

e.g. ……….ACA**T**AGA………. vs.
……….ACA**C**AGA……….

- 1 SNP for every 1000 bp in unrelated individuals



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Candidate SNP Approach

Top-Down

Cognitive Function

Regional Brain Network

Neurophysiology of Brain Area

Neurotransmitter Innervation

Neurotransmitter Modulation

Protein Regulation

Neurotransmitter SNP

SNP

SNP Databases (e.g., http://www.ncbi.nlm.nih.gov/SNP/)

Bottom-Up

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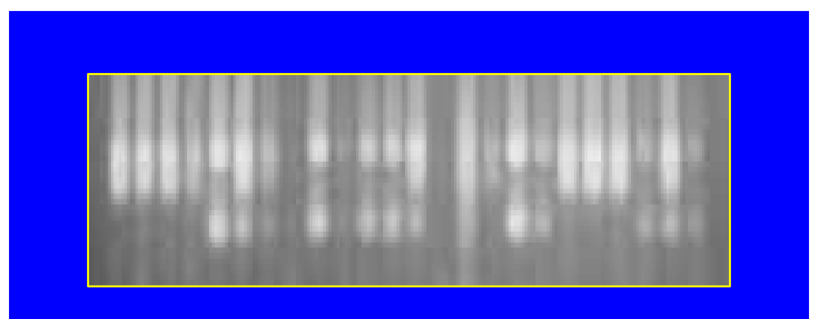
Gene SNPs Associated with Cognition

- Dopaminergic/Noradrenergic Genes
  - DRD 4
  - DAT 1
  - COMT
  - **DBH** √
- Nicotinic Cholinergic Genes
  - CHRNA4
  - CHRNA7
- Muscarinic Cholinergic Genes
  - CHRM2
- Genes Affecting Neuron Health and Plasticity
  - BDNF
  - APOE-e4

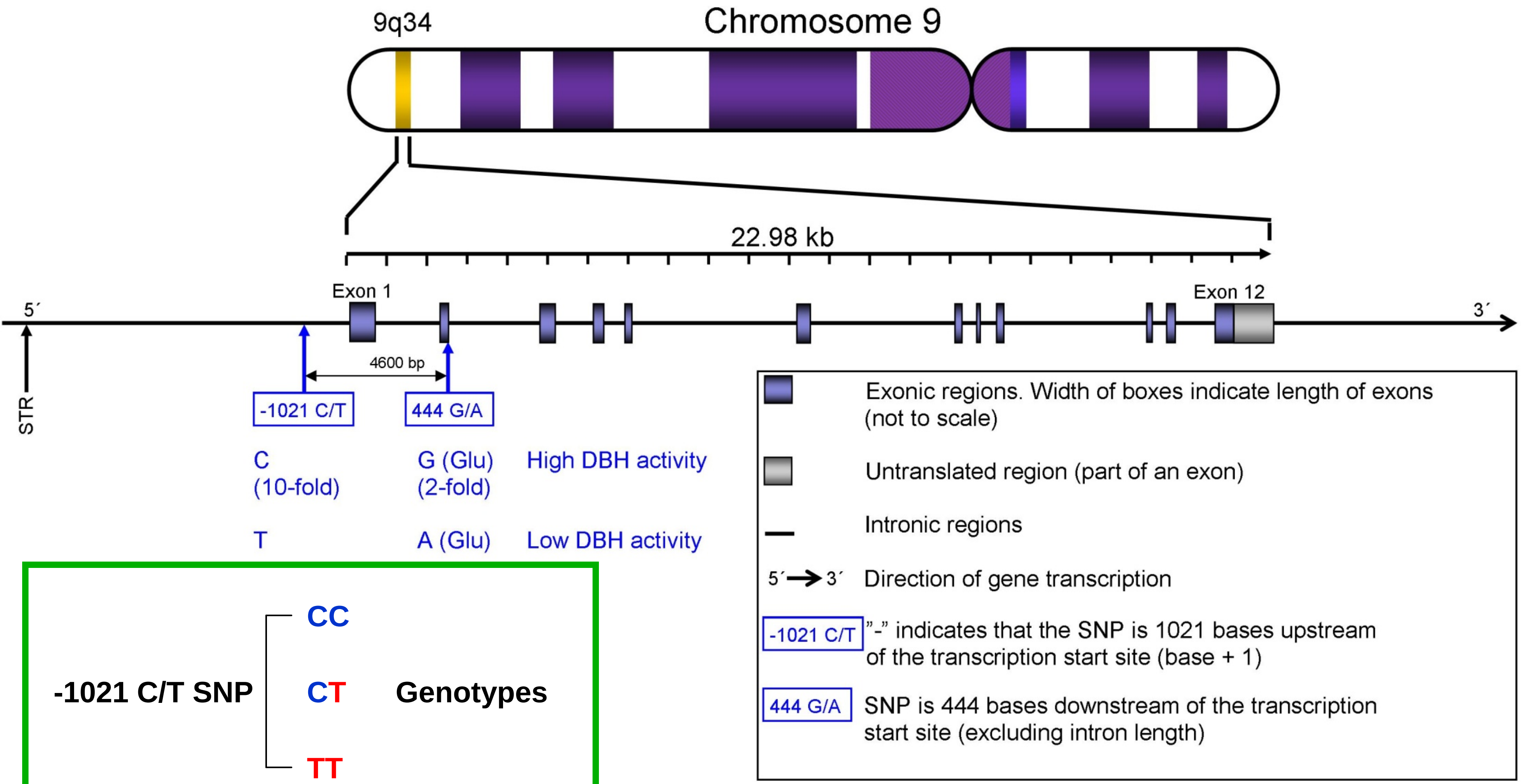
Greenwood & Parasuraman (2003). *Cognitive Neuroscience Reviews.*



Working Memory and Complex Decision Making

- Important moderating factor in many different cognitive functions—decision making, problem solving, language processing, mathematical cognition, etc.
- The dopamine beta hydroxylase (DBH) gene product converts dopamine to norepinephrine in the brain
- DBH modulation may be selective for prefrontal cortex dependent functions, such as working memory and executive function
- Do individuals with DBH gene variants
  - Have high working memory capacity?
  - Exhibit higher decision accuracy under time pressure?

The DBH Gene and its SNPs

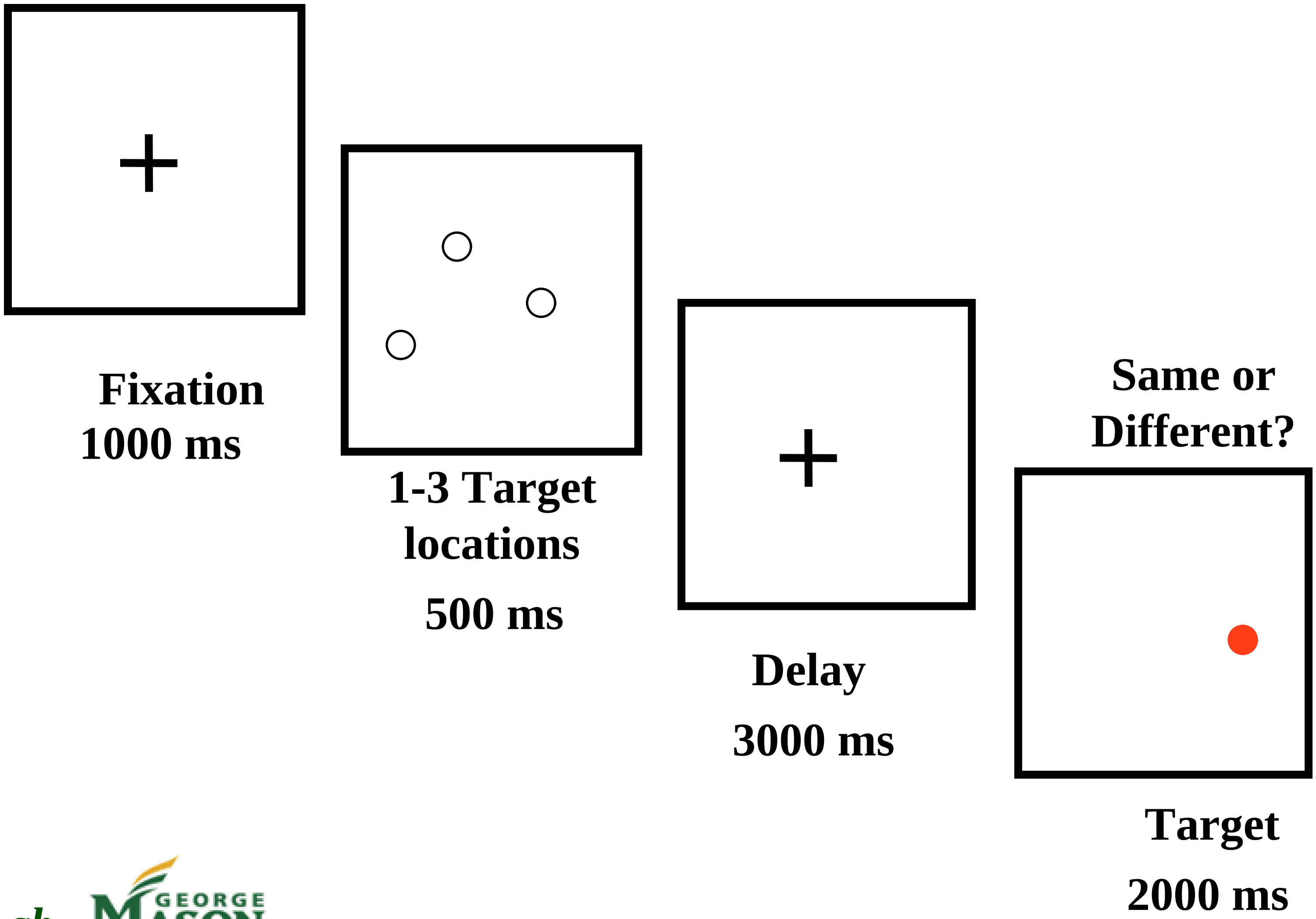


-1021 C/T SNP

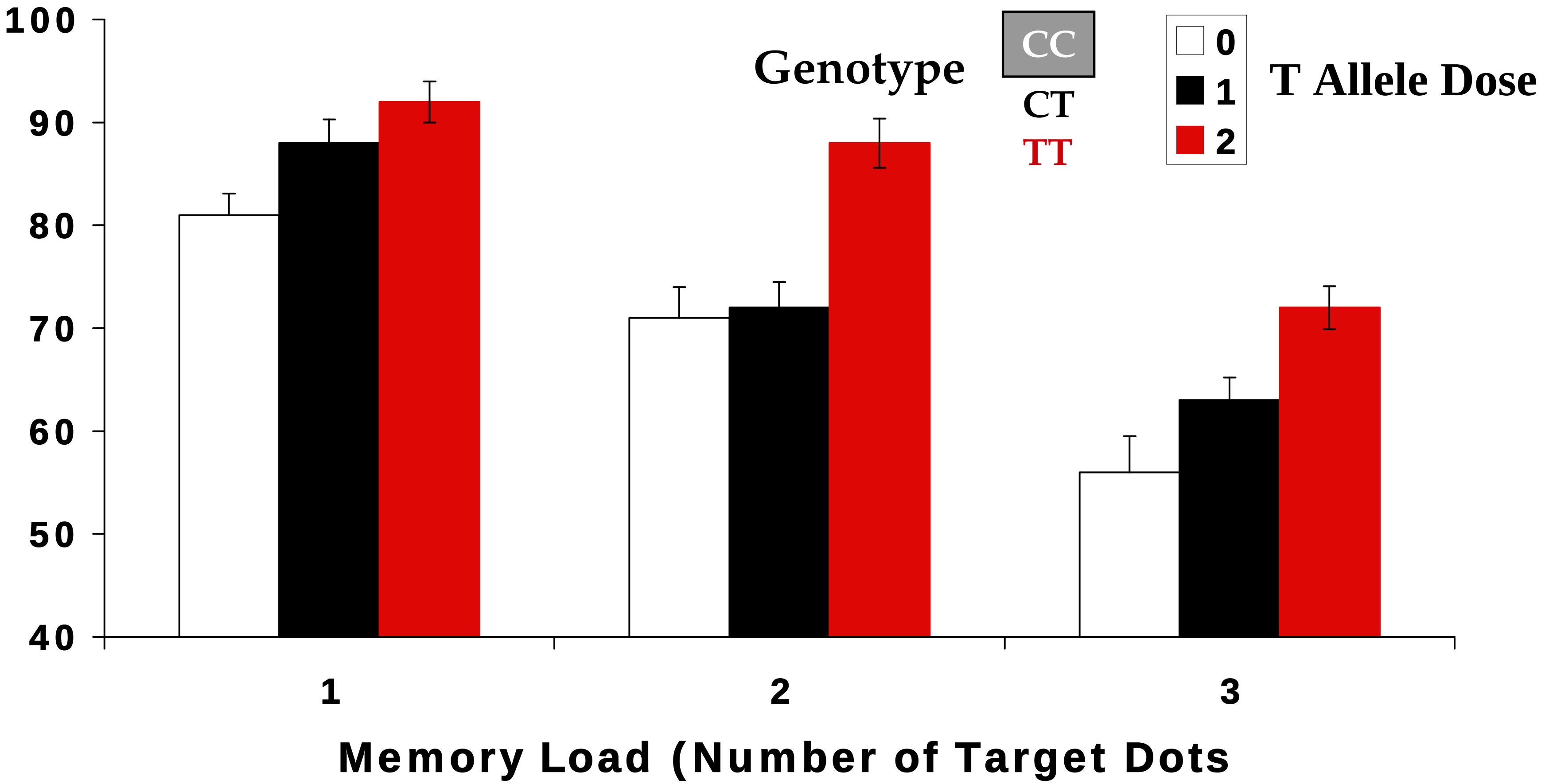
- **CC**
- **CT**
- **TT**

Genotypes

Working Memory Task



Effects of T Allele Dose of DBH -1021 C/T SN
on Spatial Working Memory



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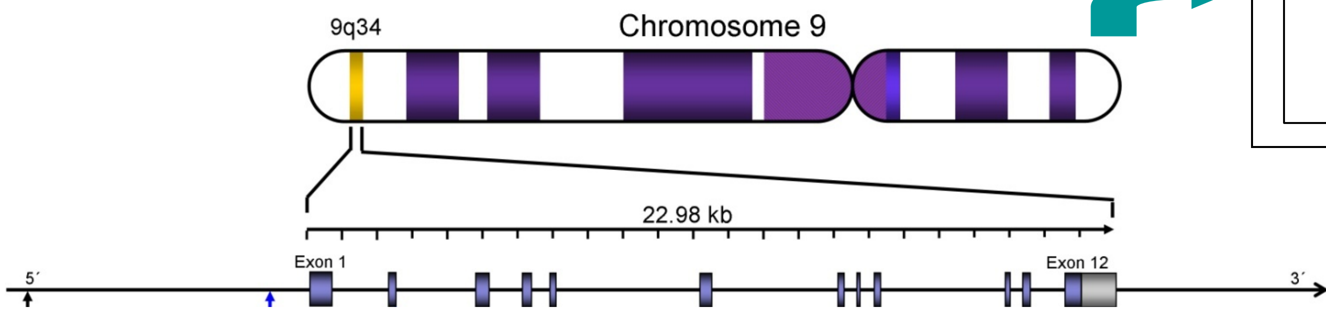
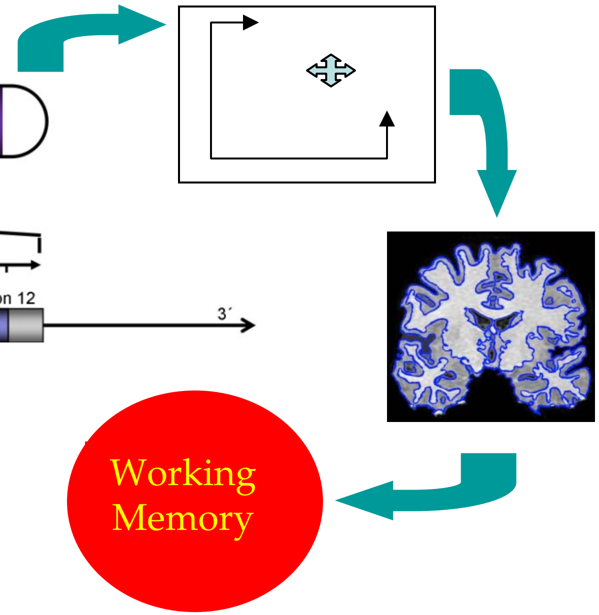
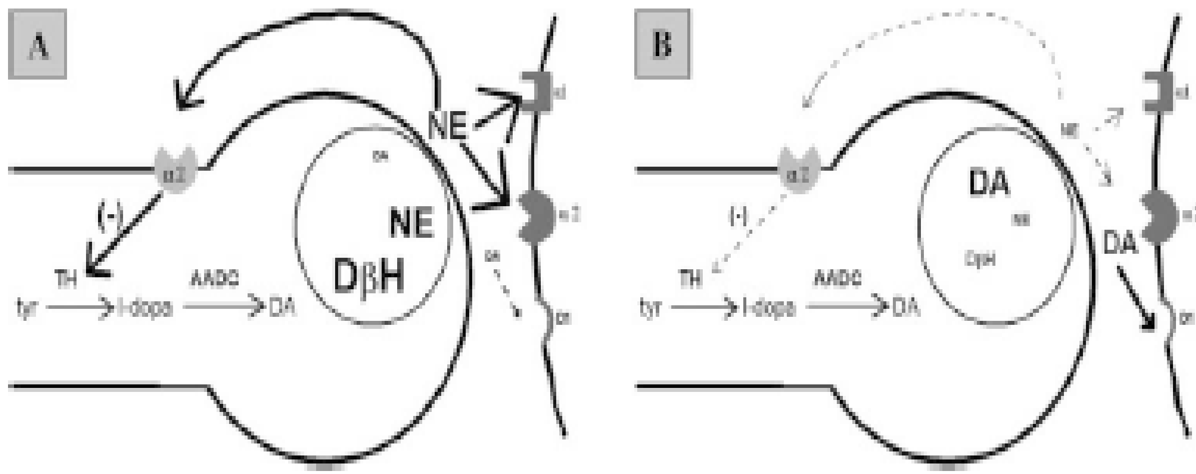




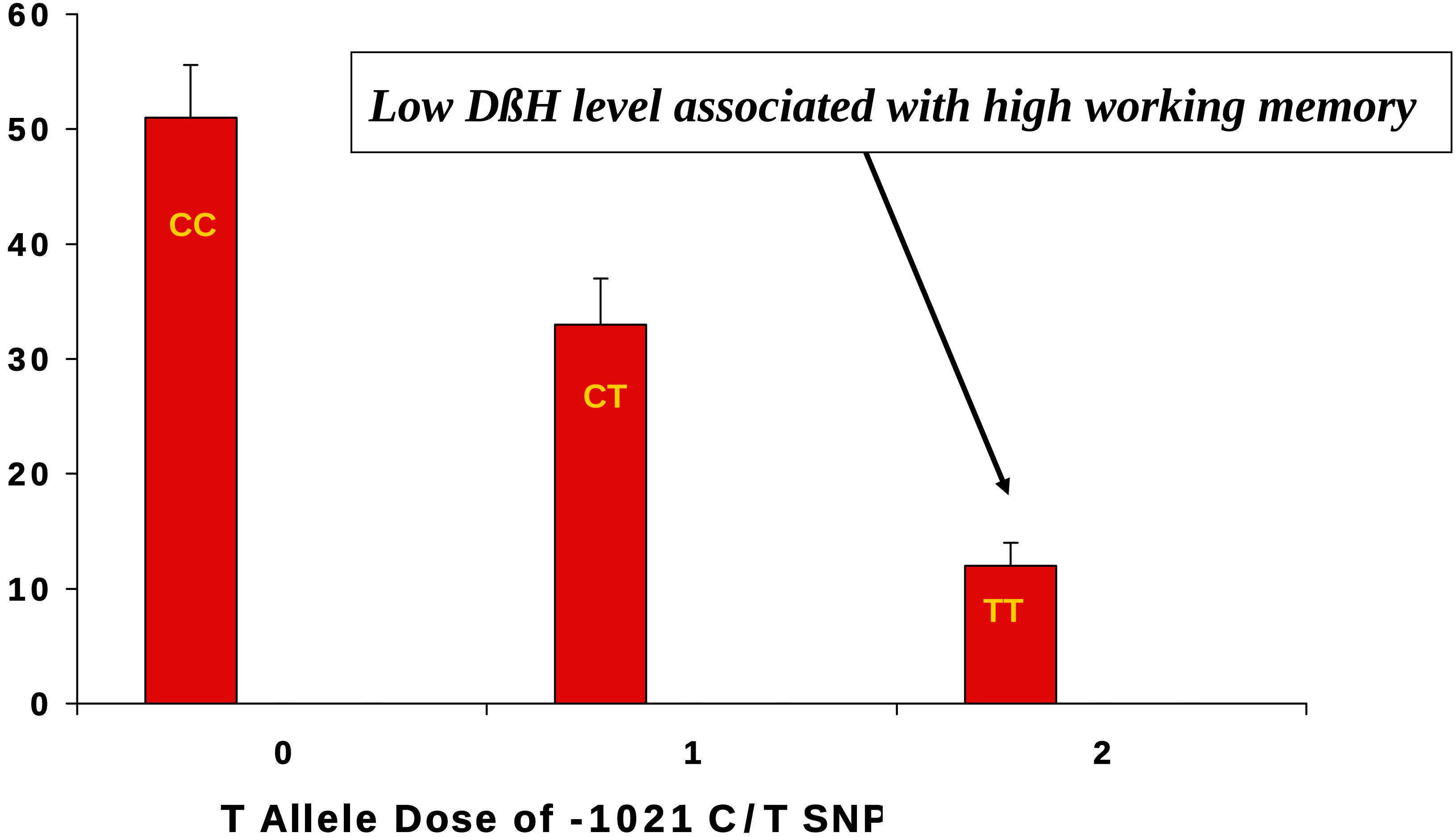
- **What is the mechanism by which DBH is linked to working memory?**
- **Is DBH a "functional" SNP?**
- **Genes are only of interest if they are *expressed* and influence proteins, particularly in the brain**
- **Cognitive proteomics: linking gene-controlled proteins to function**

Effects of DßH on Synaptic Dopamine (DA) and Norepinephrine (NE)

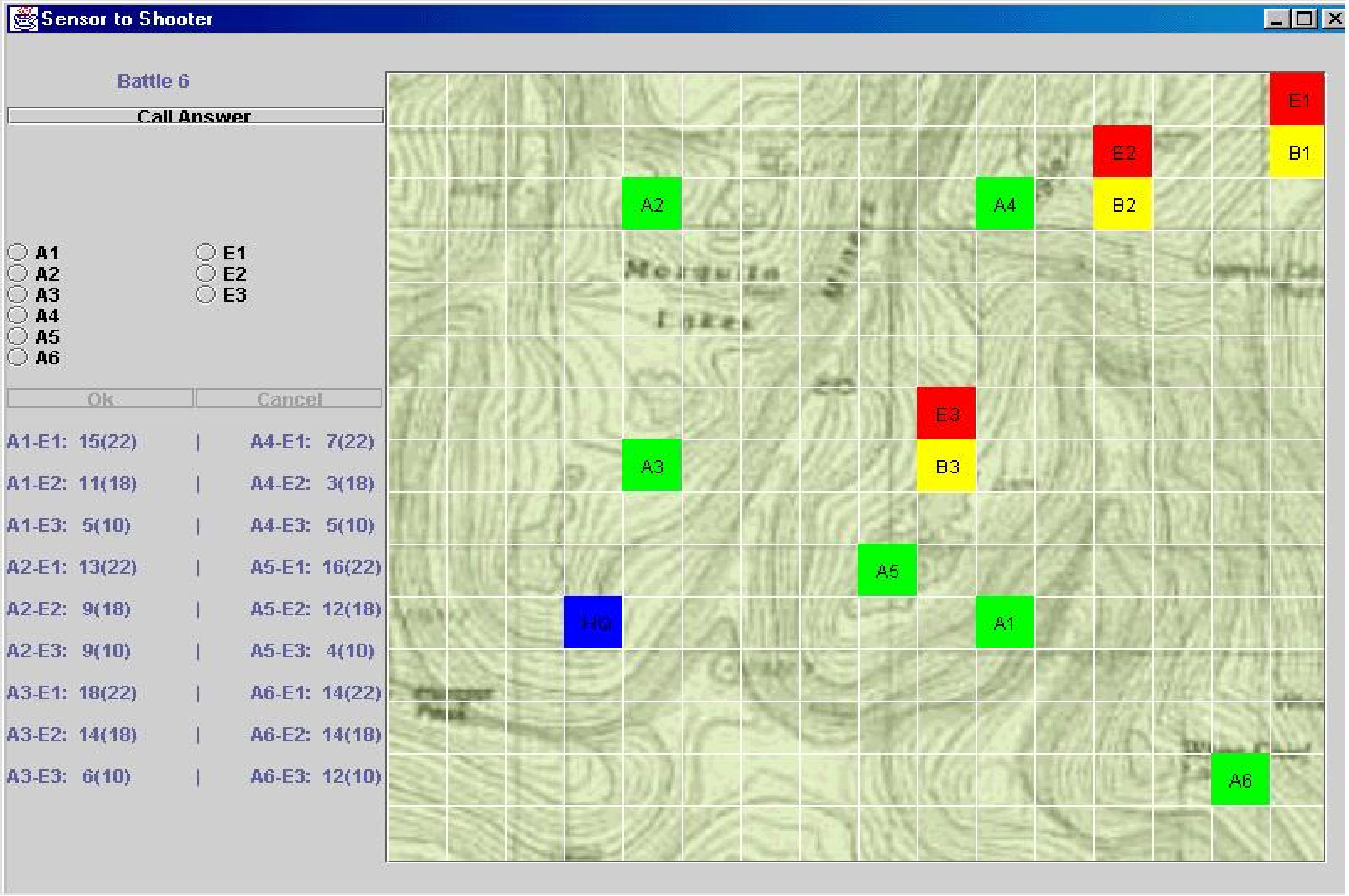
- A. High DßH Level: NE receptors active
- B. Low DßH Level: DA receptors active



Effects of T Allele Dose of DBH -1021 C/T SNP on Plasma Dopamine ß Hydroxylase Levels



Decision Making in Command and Control



Decision making task performed both with and without automated support

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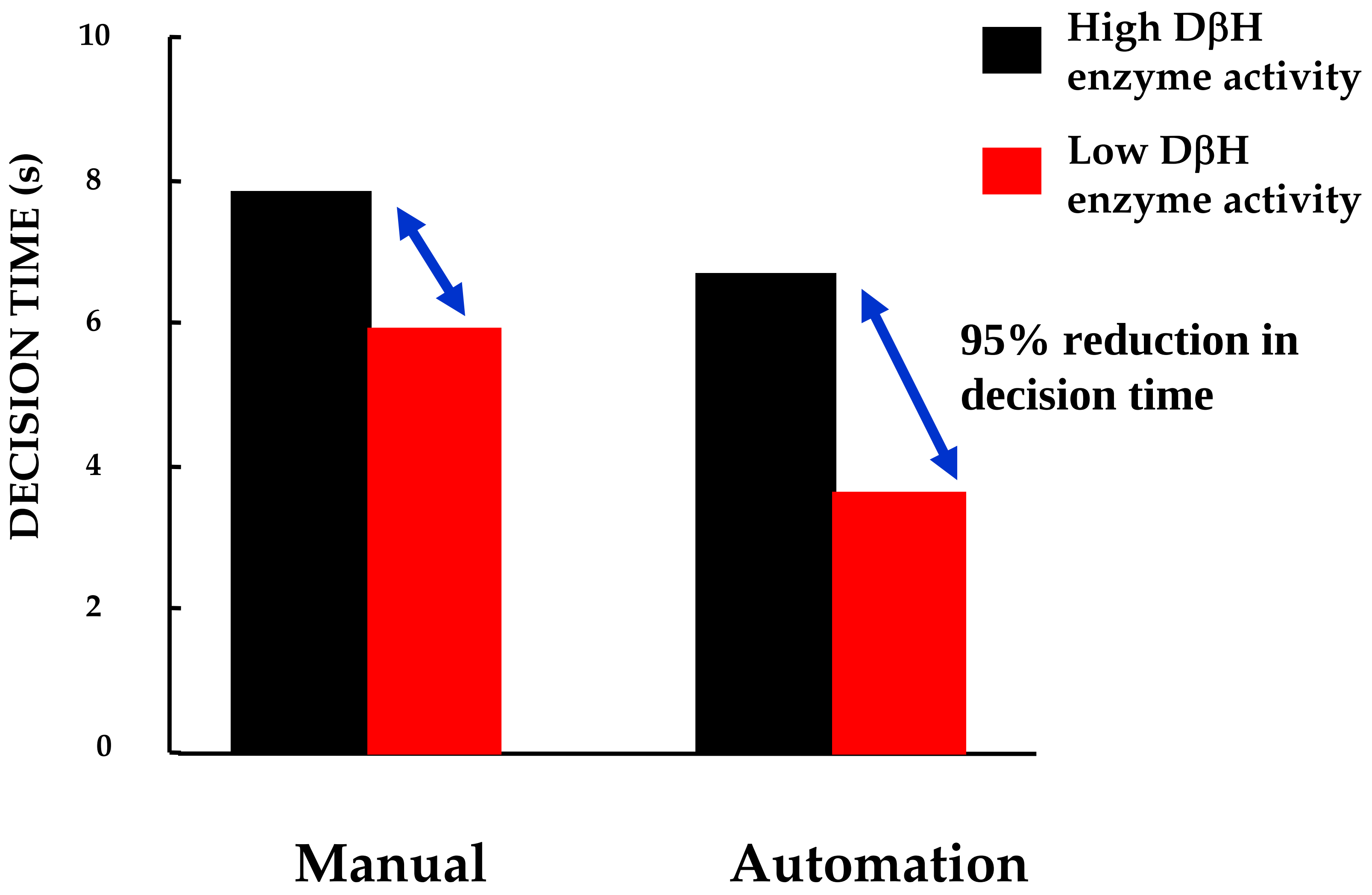
DβH Enzyme Levels and Decision Time



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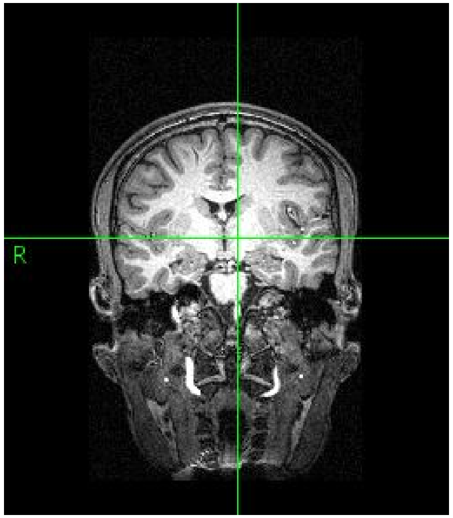
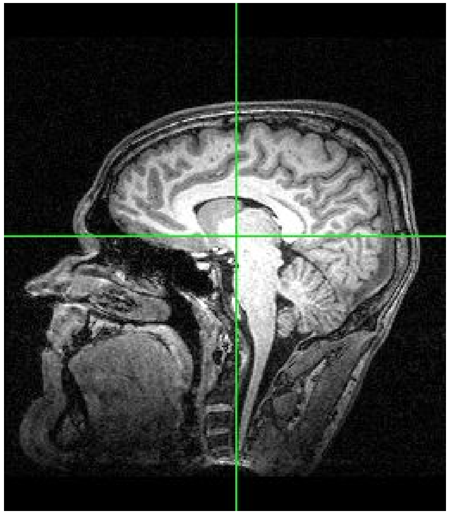
Subject 7: A “Cognitive Superstar”

- Has very high verbal and spatial working memory—4 standard deviations above average
- Can maintain attention at 100% accuracy for 2 hours
- Shows *reduced* prefrontal fMRI activation and *no increase* with load in a working memory task
- What are S7’s DBH genotypes?
- S7 has the T/T genotype in the -1021 C/T SNP associated with high working memory and low DßH enzyme level
- Has lowest blood DßH enzyme level among 650 subjects tested to date

What Else Do We Know About S7?



- Age 26, Male Graduate Student
- High-average but not superior IQ
- Good but not exceptional grades
- Normal MRI (volumetric analysis of specific cortical regions not done)
- NOT an avid video game player (cf. Daphne Bavalier studies on attentional capacity)



Example 2: Conclusions

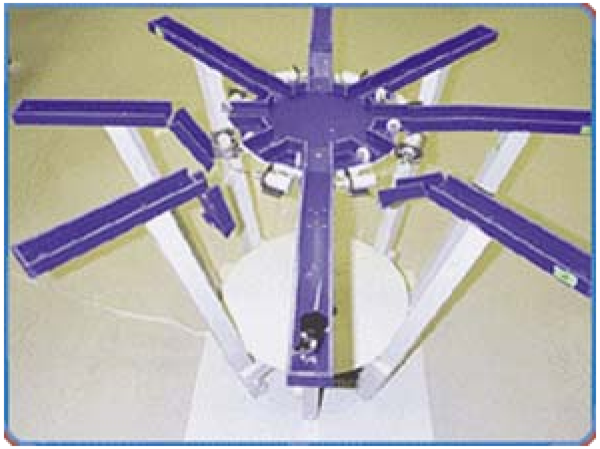
- DBH—a dopaminergic/noradrenergic gene expressed strongly in prefrontal cortex—associated with normal individual differences in working memory (verbal and spatial)
- Plasma DßH levels inversely correlated with working memory and decision making performance
- Molecular genetics provides a new approach to understanding
  - individual differences in cognition
  - exceptional cognitive performance

Ongoing Research

- **Gene-gene interactions**
  - Effects of cholinergic (CHRNA4) and neurotrophic (Alzheimer risk) genes (APOE) on attention
  - Interactive effects of nicotinic (CHRNA4) and muscarinic (CHRM2) genes on attention
- **Gene-environment interactions**
  - Effects of COMT and DBH and variable-priority training on dual-task performance
  - Moderating influence of COMT and BDNF genes on effects of aerobic exercise on executive attention in older adults

Ongoing Research

- Spatial working memory in normal and DBH ---1021T/C knockout mice
- RNA interference studies in rat model of aging (Fischer 344 strain, Bizon group)



Neuroergonomics: Conclusions

- Neuroscience is not a panacea to the challenges facing the Army
  - but appropriately applied neuroscience
  - that goes beyond the bench to examine complex cognitive functions of humans performing real work in real settings—*Neuroergonomics*
  - can yield great benefits in enhancing soldier and system performance
- Two examples of successful neuroergonomics research
  - Neuroimaging and adaptive automation
  - Molecular genetics and proteomics
- Neuroergonomics can lead to more effective and natural interaction between humans and technology